Modeling the ecological effects of endocrine active compounds on fish: Scaling from individuals to populations

Kenneth A. Rose[1], Cheryl A. Murphy[2], Peter Thomas[3], Lee A. Fuiman[3], Maria C. Alvarez[3], Ian D. McCarthy[4], and Sandra L. Diamond[5]

[1]Department of Oceanography and Coastal Sciences, Louisiana State University, Baton Rouge, LA USA
[2]Department of Zoology, University of Toronto, Toronto, Ontario, Canada
[3]Marine Science Institute, University of Texas, Port Aransas, TX, USA
[4]School of Ocean Sciences, University of Wales-Bangor, Anglesey, UK
[5]Department of Biology, Texas Tech University, Lubbock, TX, USA

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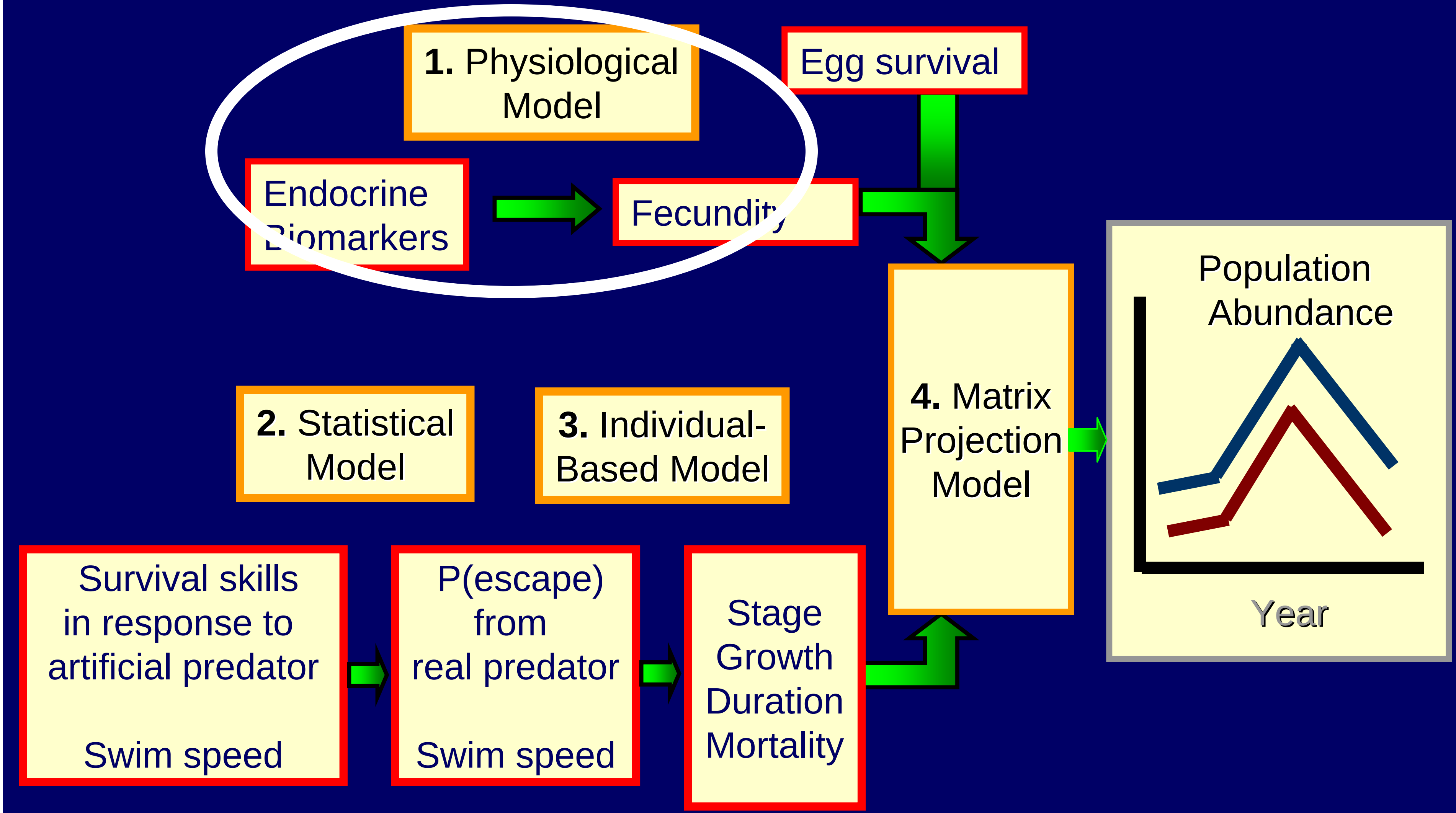
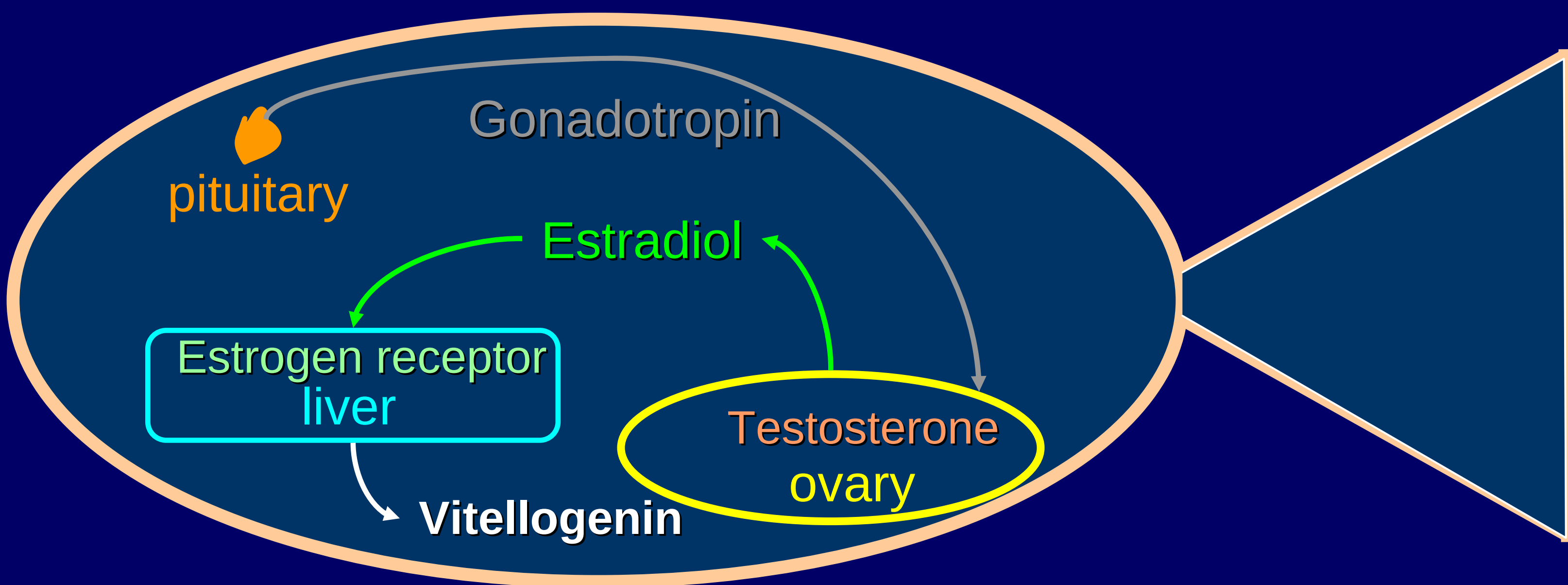
Methods - Outline

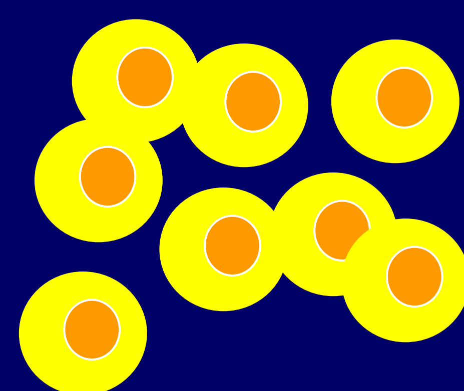


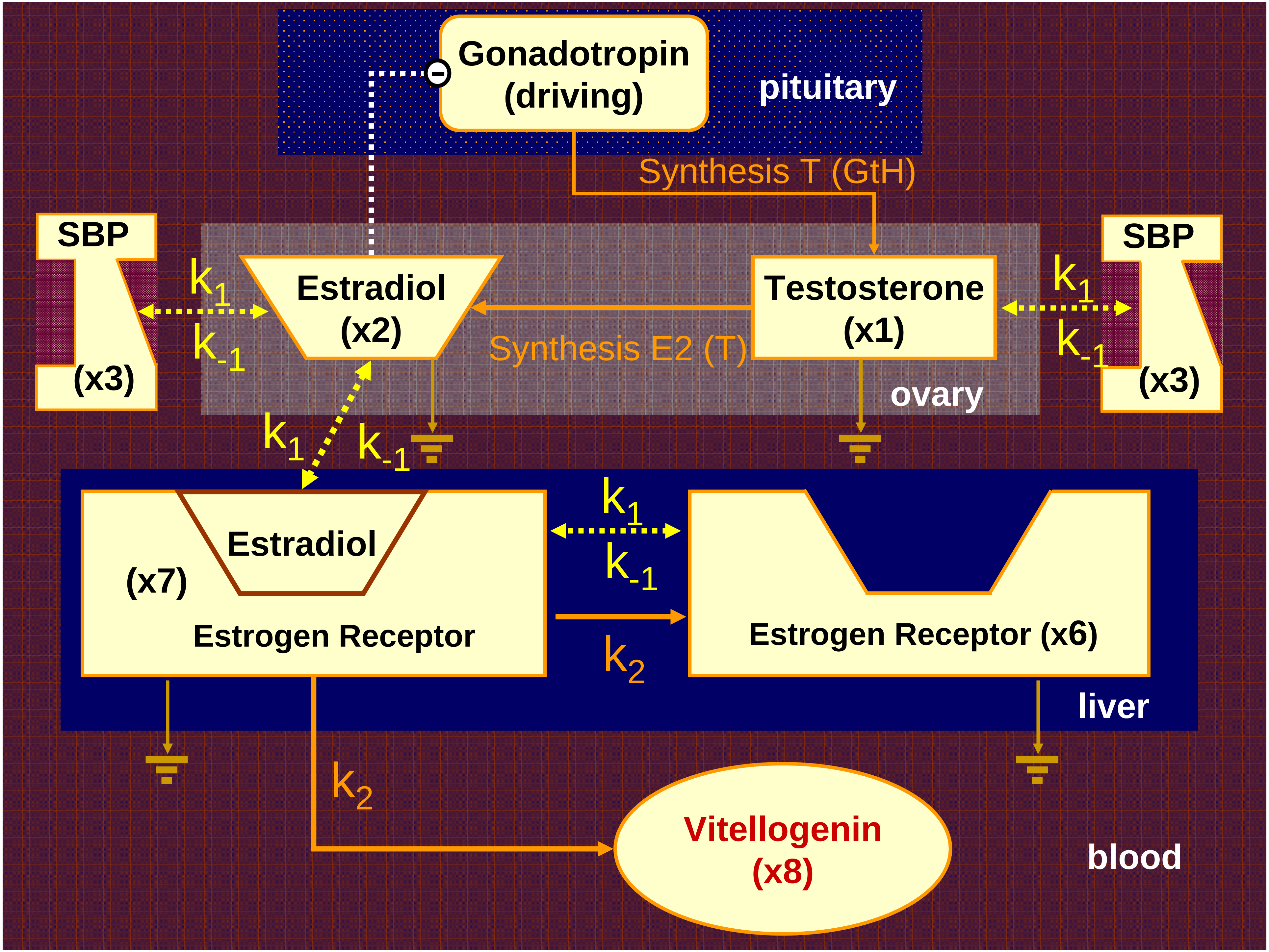
Scaling Biomarkers to Reproductive Endpoint



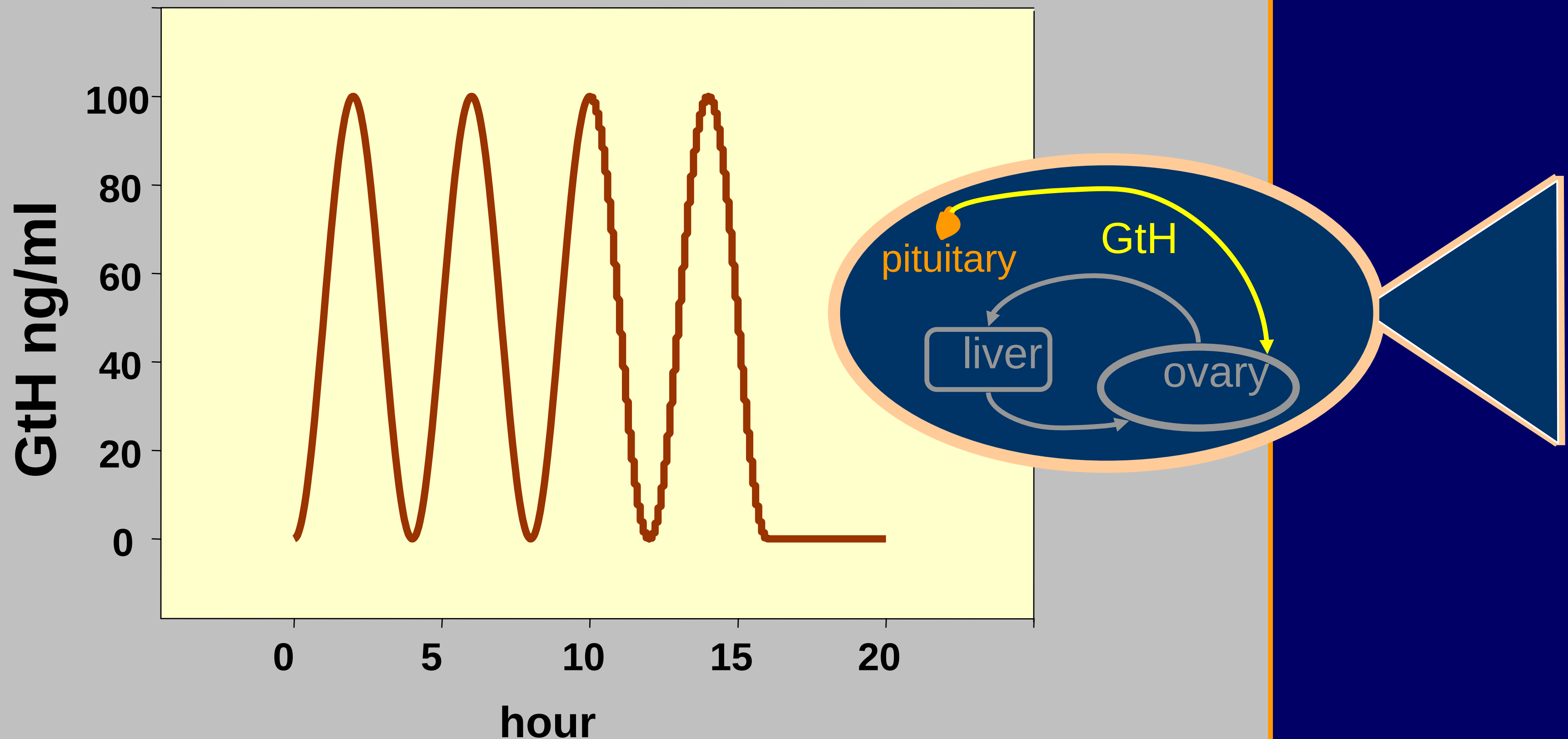
Gonadotropin = GtH
Testosterone = T
Estradiol = E2
Estrogen Receptor = ER
Vitellogenin = Vtg
Gonadal Somatic Index = GSI

Viable Oocytes




Gonadotropin
(driving)
pituitary
Synthesis T (GtH)
SBP
(x3)
k1
k-1
Estradiol
(x2)
Synthesis E2 (T)
Testosterone
(x1)
k1
k-1
SBP
(x3)
ovary
k1
k-1
Estradiol
(x7)
Estrogen Receptor
k1
k-1
k2
Estrogen Receptor (x6)
liver
k2
Vitellogenin
(x8)
blood

Gonadotropin - Driving variable



$$GtH = 50(1 - 10\cos\frac{2\pi(t)}{4})$$

Model - Series of Ordinary Differential Equations

$$\frac{dT}{dt} = \text{synT}(\text{GtH}) - \text{synE2}(\text{T})$$

$$\frac{dE2}{dt} = \text{synE2}(\text{T}) + k_{-1}[\text{E2ER}] - k_1[\text{E2}][\text{ER}]$$

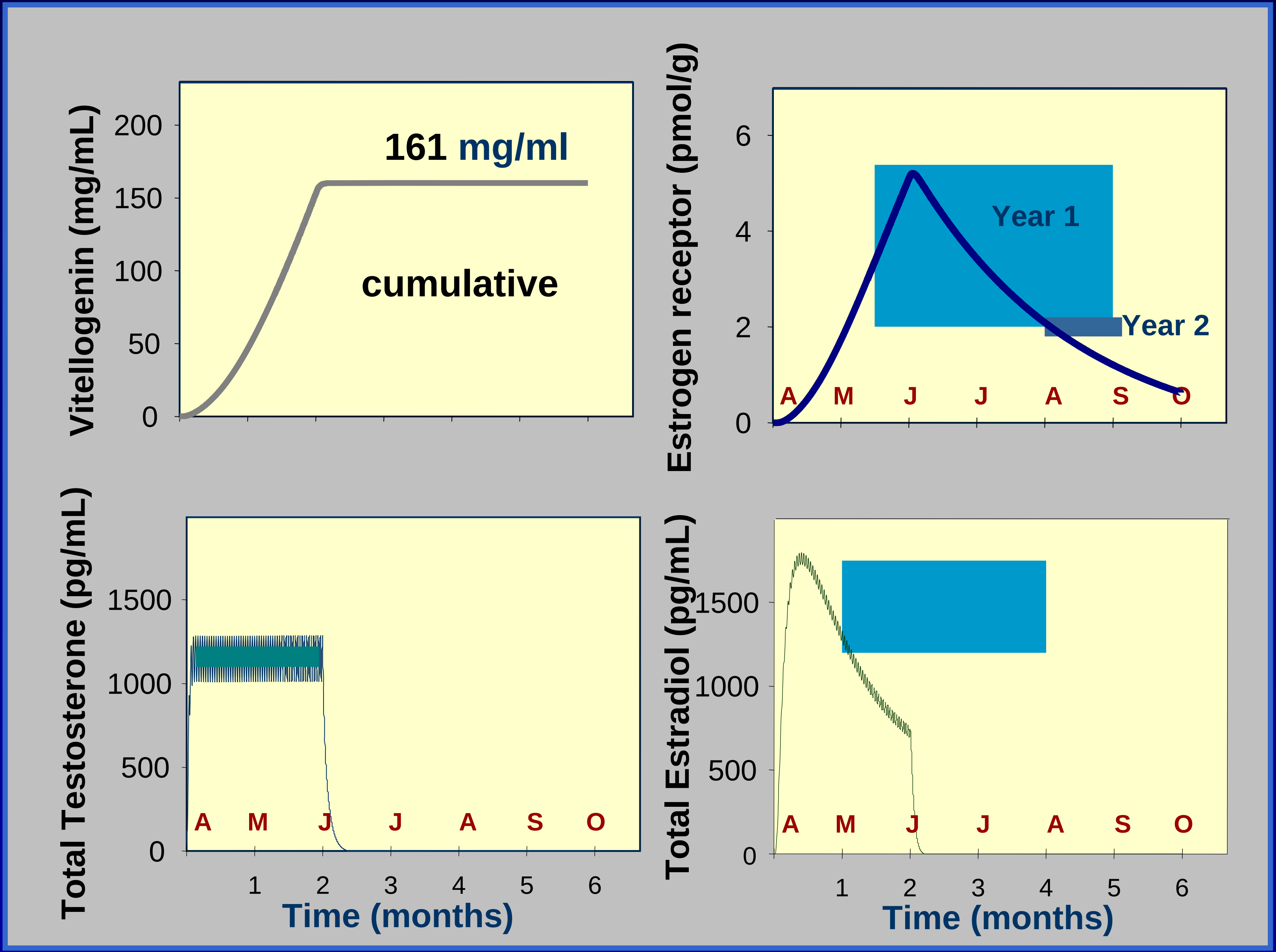
$$\frac{dER}{dt} = -k_1[\text{E2}][\text{ER}] + (k_{-1} + 2k_2)[\text{E2ER}]$$

$$\frac{dE2ER}{dt} = k_1[\text{E2}][\text{ER}] - (k_{-1} + k_2)[\text{E2ER}]$$

$$\frac{dVtg}{dt} = k_2[\text{E2ER}]$$

Baseline Simulation

SPOTTED SEATROUT
Smith and Thomas,1991
Gen. Comp. Endocrinol.
81:234-245



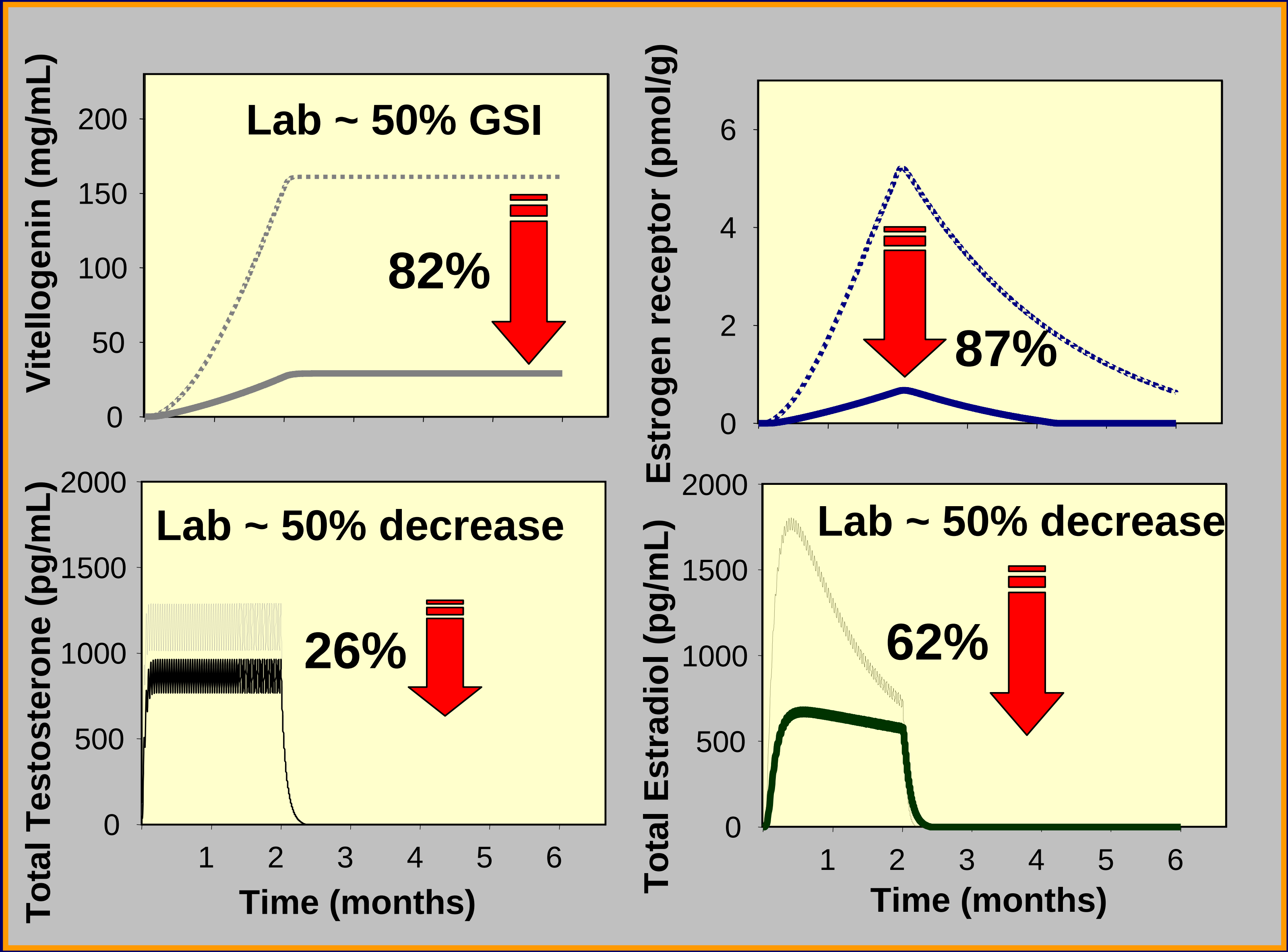
PCB Simulation

- Croaker exposed to PCBs have GtH levels that are 38% of control fish

- Multiply GtH driving variable by 0.38

PCB Mixture Simulation

ATLANTIC CROAKER
Thomas, 1989. Mar. Environ. Res. 28:499-503



Cadmium Simulation

Cadmium increases GtH secretion by 295%

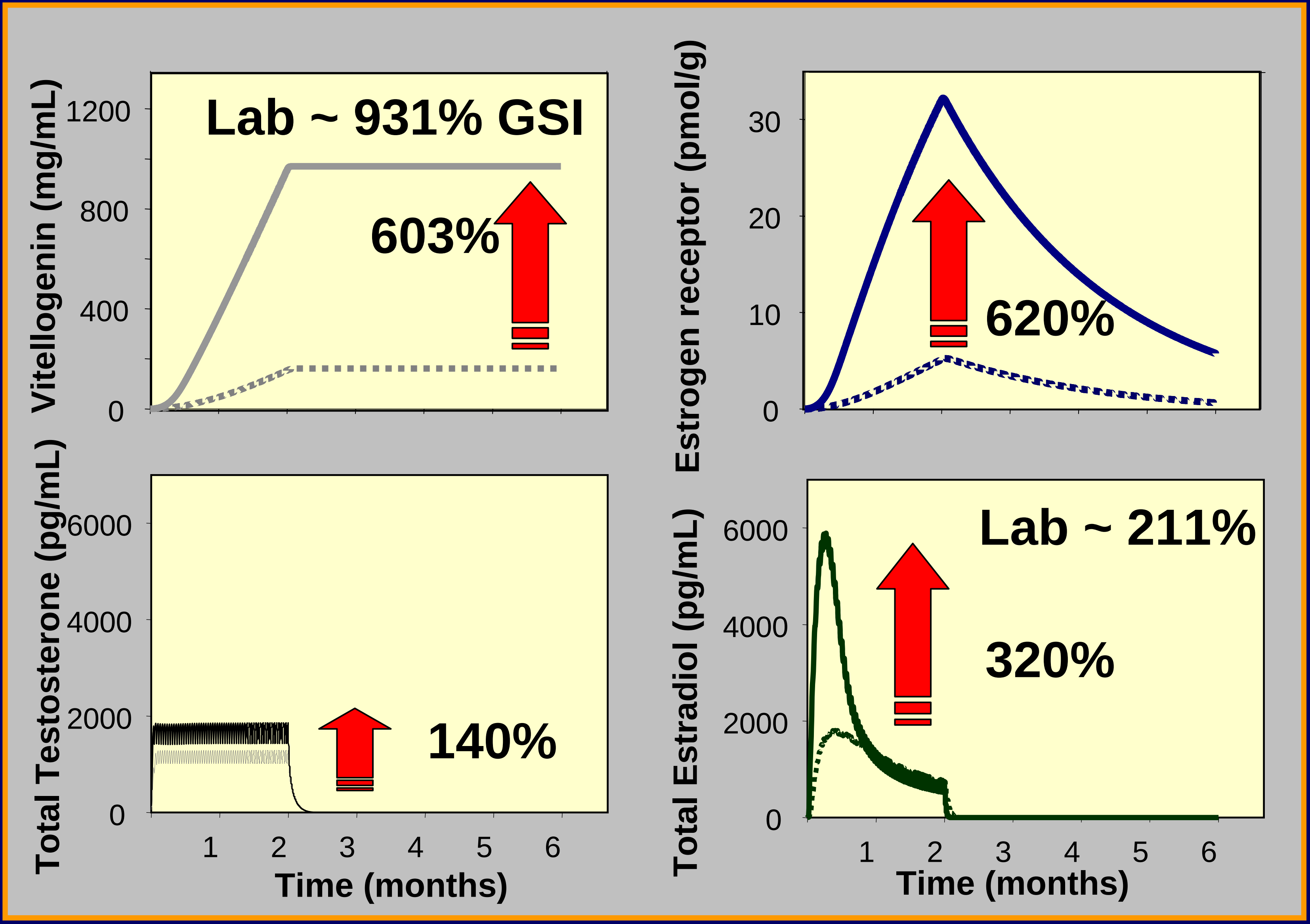
- Multiply GtH driving variable by 2.95

Cadmium doubles the rate of testosterone production

- Multiply testosterone synthesis function by 2.0

Cadmium Simulation

ATLANTIC CROAKER
Thomas, 1989. Mar. Environ. Res. 28:499-503

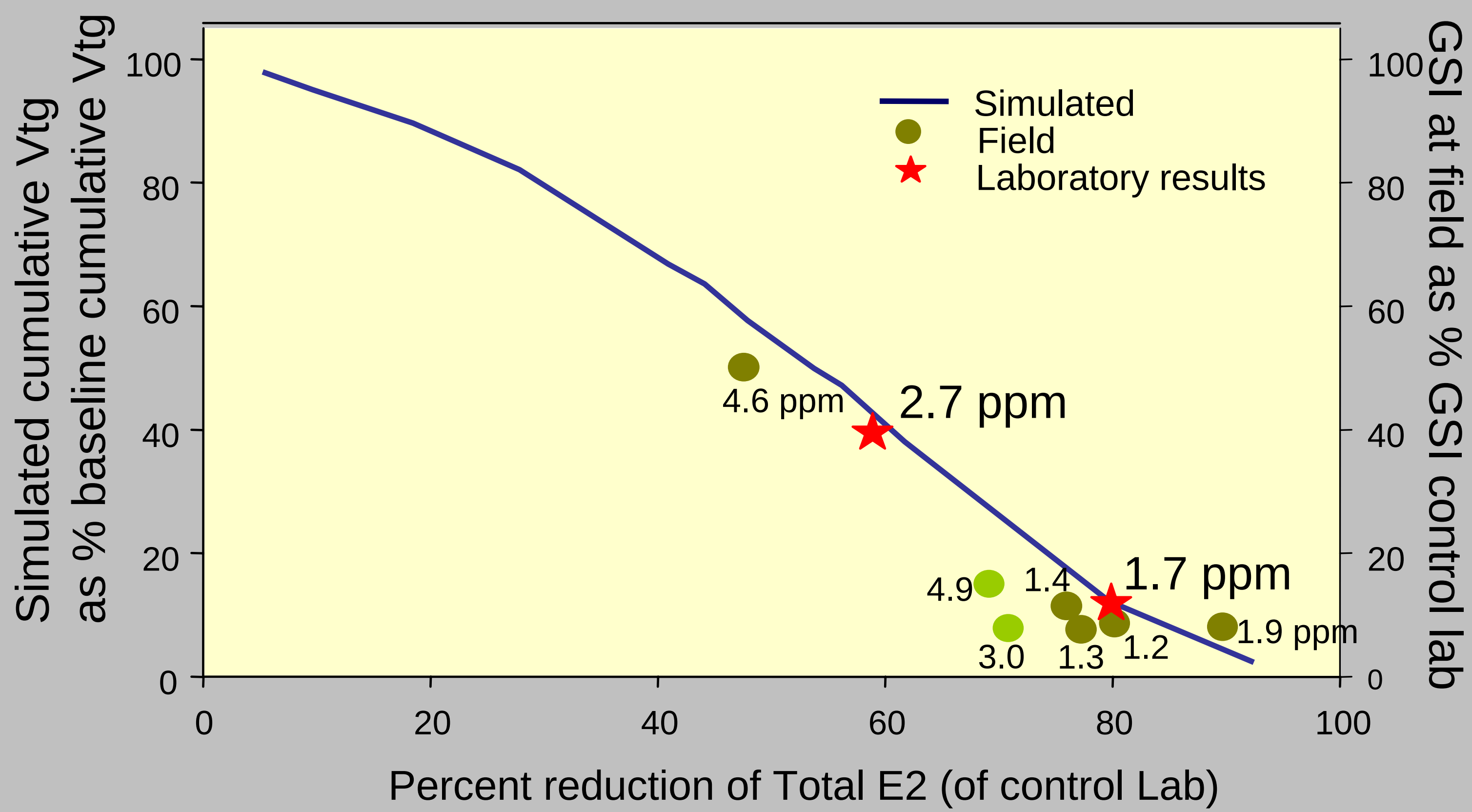


Field Evaluation

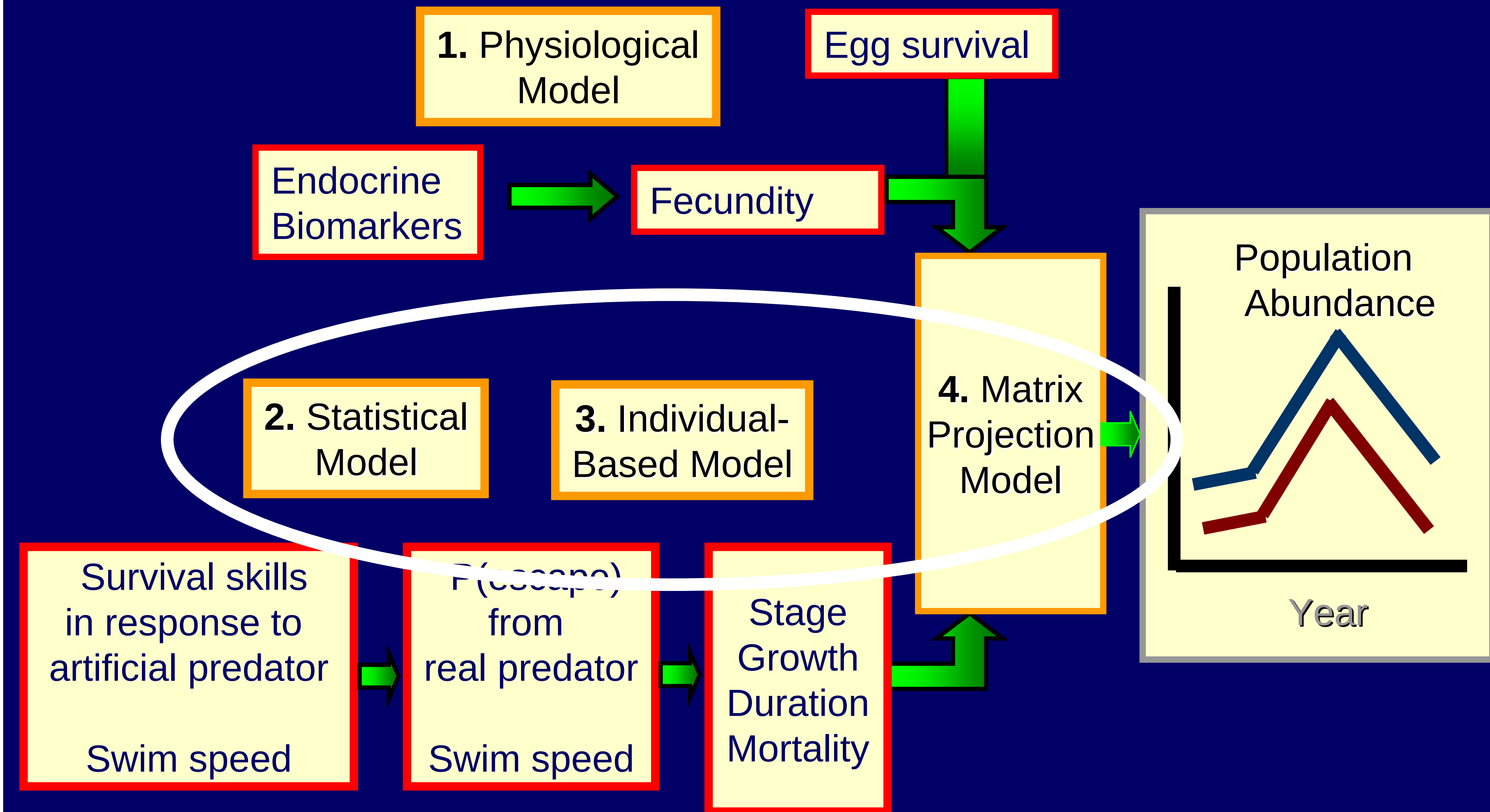
Determine if biomarkers measured in field indicate exposure to hypoxia

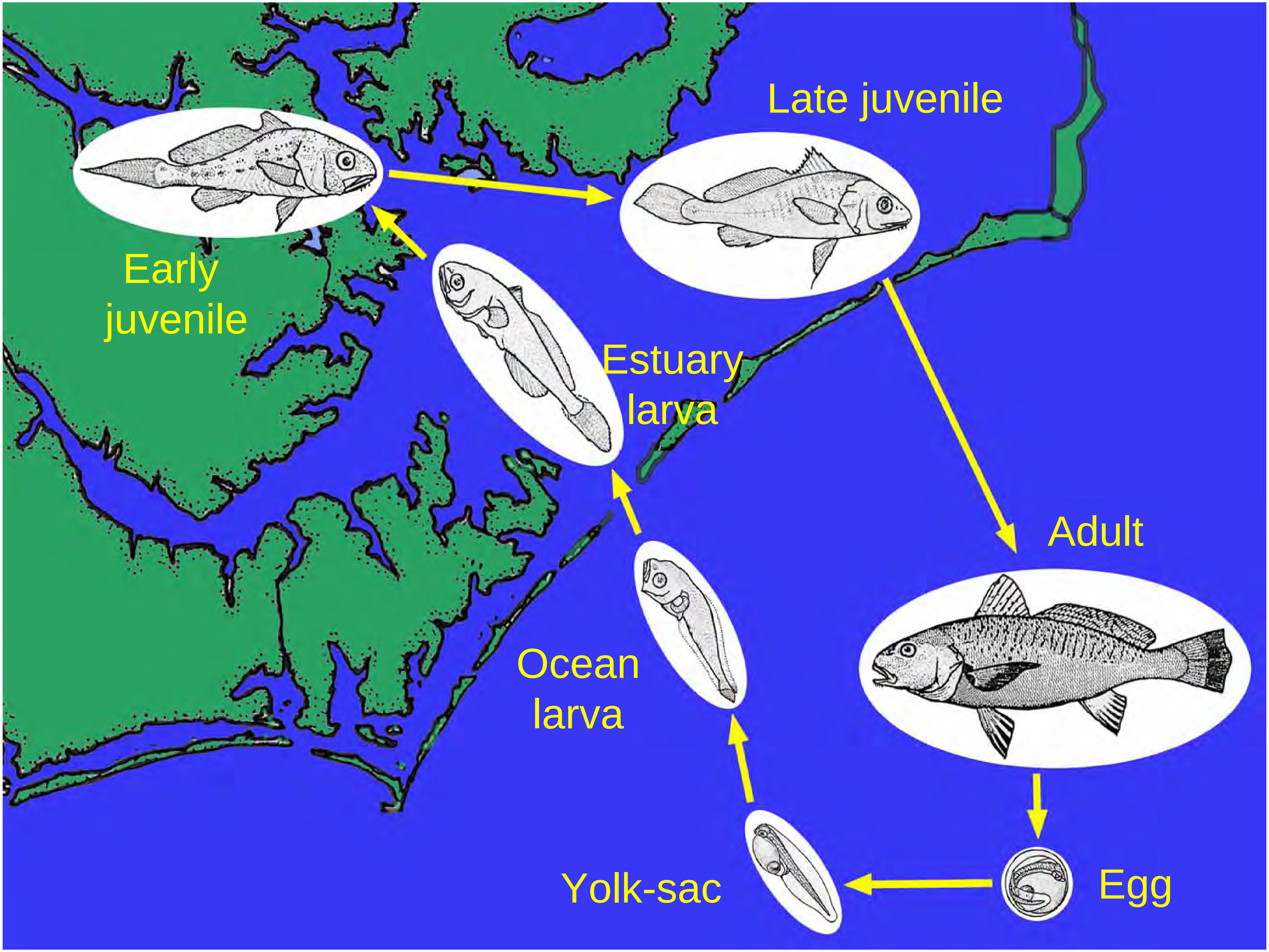
- Simulate cumulative vitellogenin production with decreasing estradiol
- Compare to laboratory studies
- Compare to fish undergoing gonadal development that were collected from sites with varying degrees of hypoxia

Field Evaluation



Methods - Outline



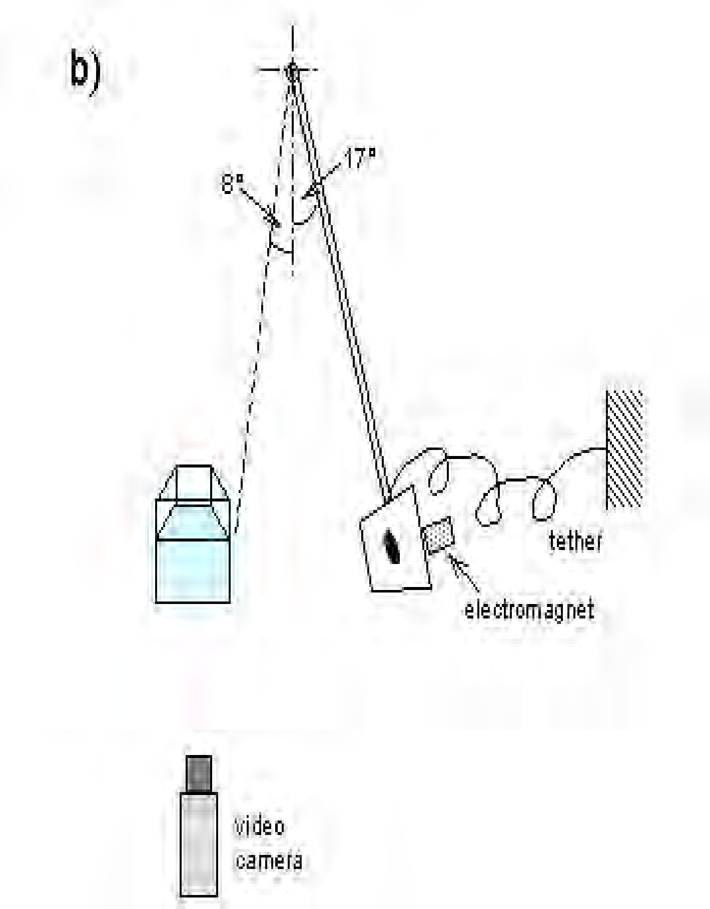

Late juvenile
Early
juvenile
Estuary
larva
Adult
Ocean
larva
Yolk-sac
Egg

Fish Behavior

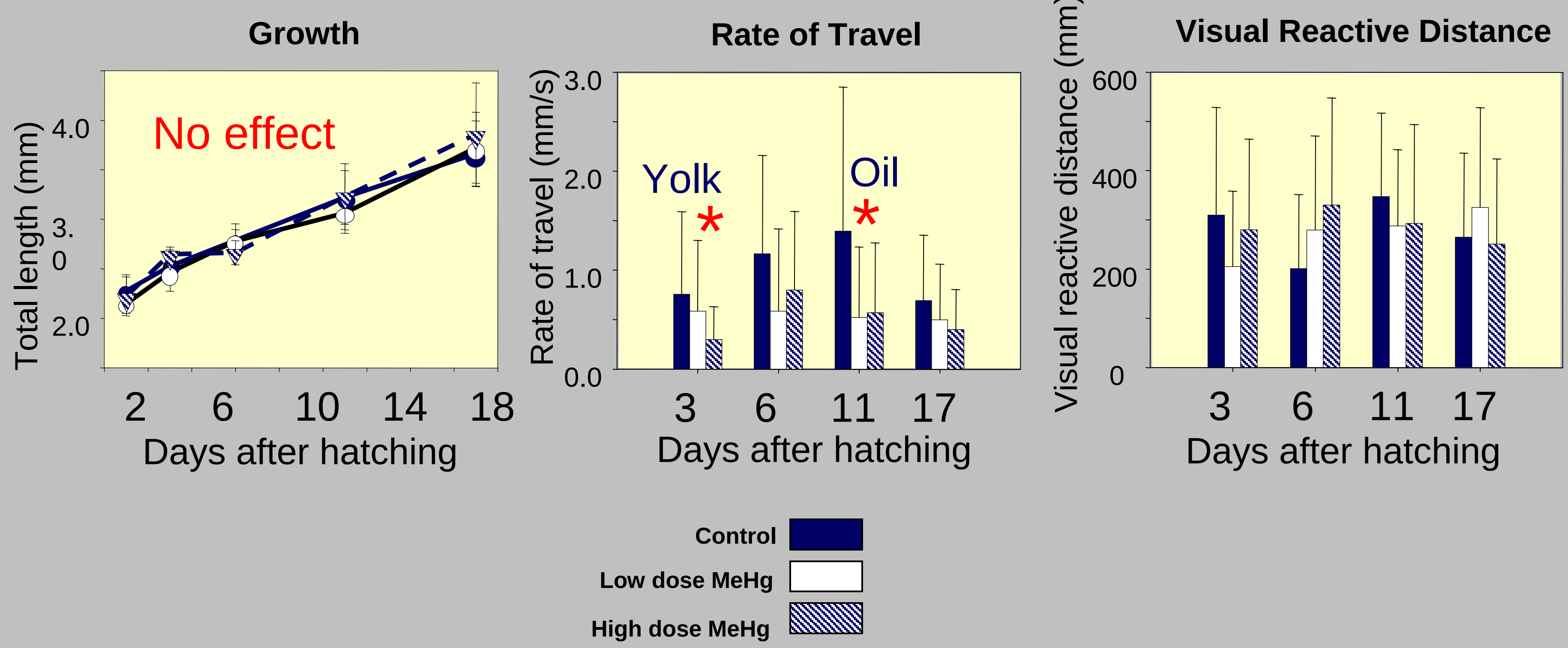
- Behavior often used as a toxicological endpoint
- Effects of contaminants on fish behavior well documented
- Difficult to quantitatively extrapolate contaminant effects on fish behavior to the population level

Overview of Approach

- Video-taped croaker larvae responding to fake predator attacks (survival skills)
- Control, low dose PCBs, low and high dose MeHg conditions
- Experiment with red drum where measure survival skills and also success with a real fish predator
- Statistical model: relate survival skills of croaker to probability of escaping a real predator

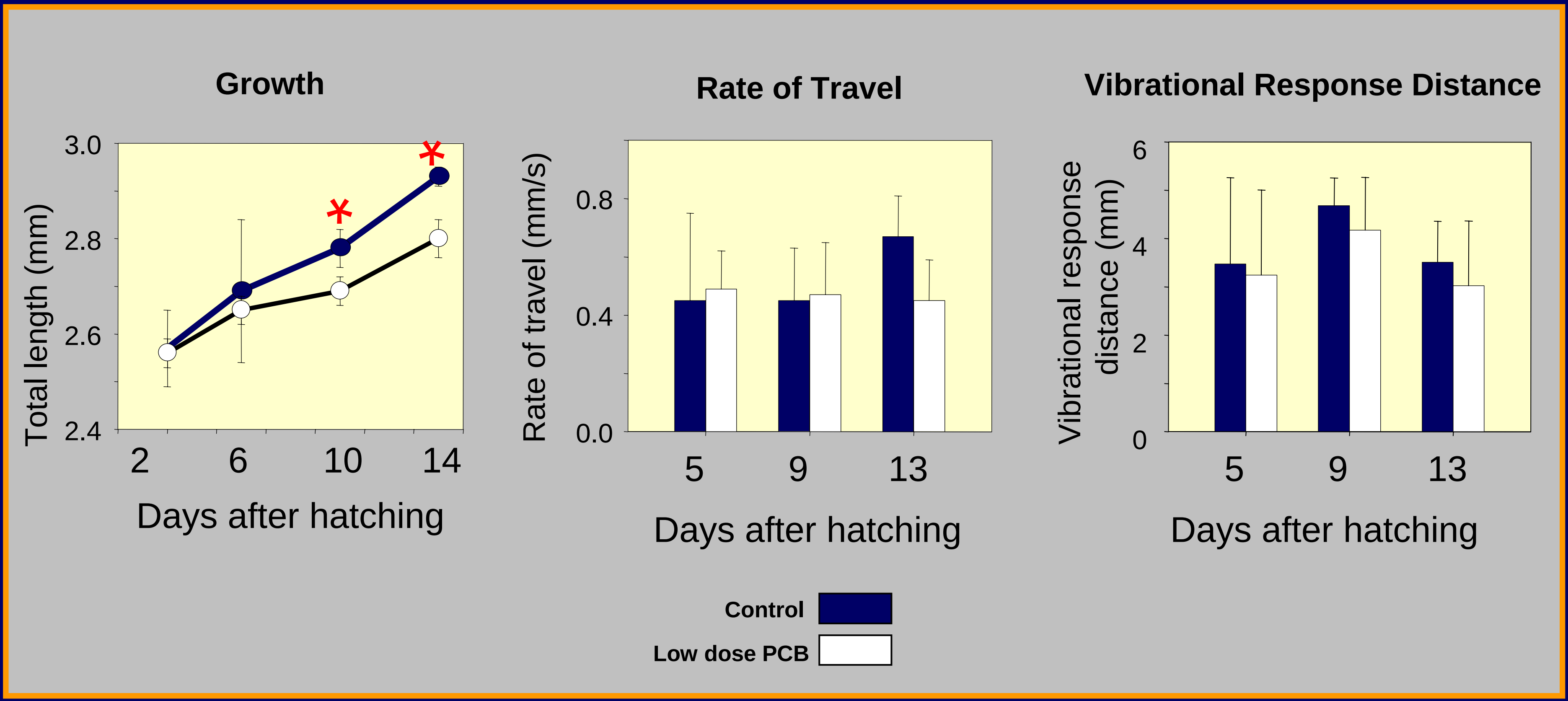


MeHg Laboratory Results



Alvarez, 2005

PCB Laboratory Results



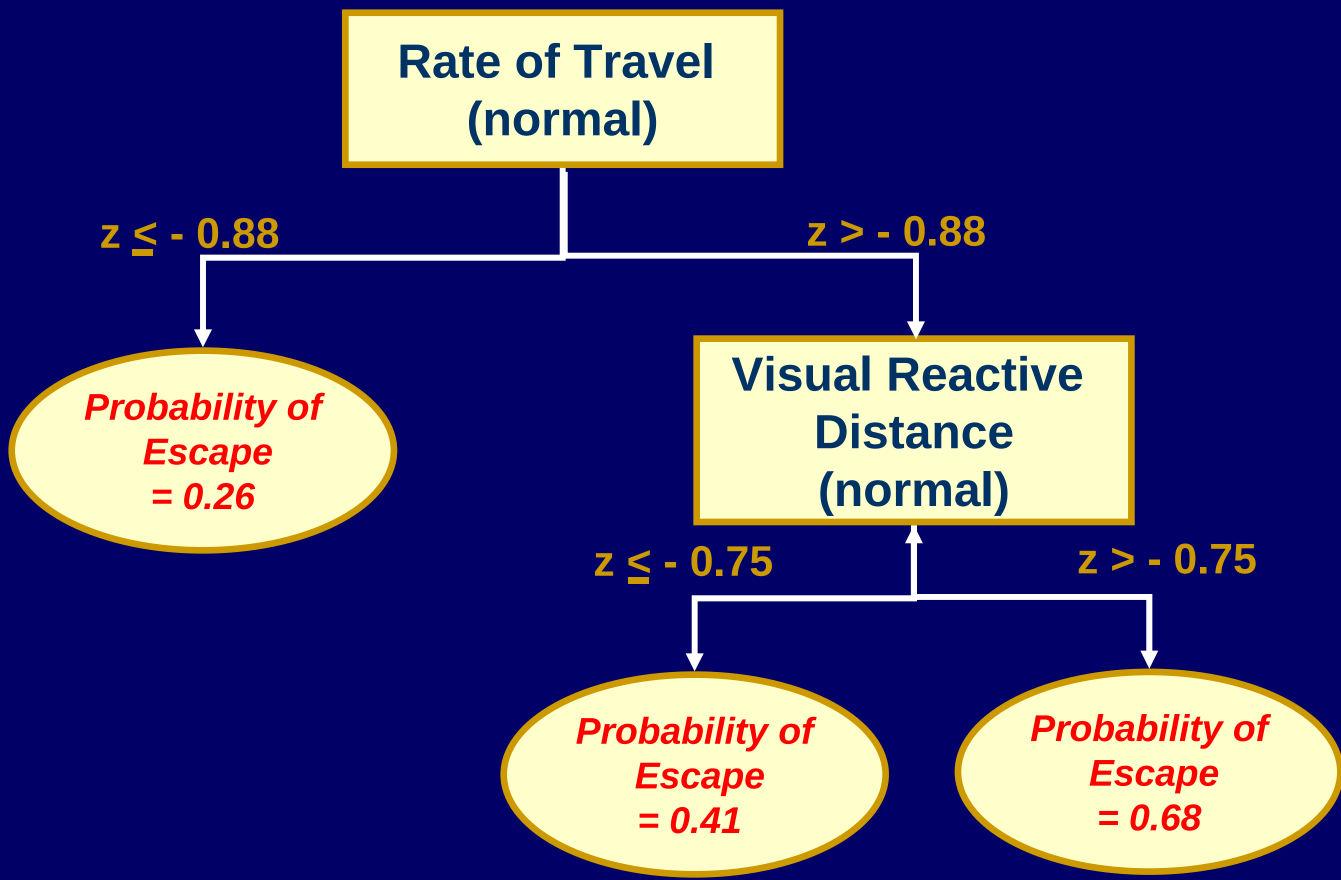
McCarthy et al, 2003

2. Statistical Models

- Regression Tree
  – Relate survival skills to probability of escaping a real predator by recursively partitioning data into a hierarchial succession of nodes

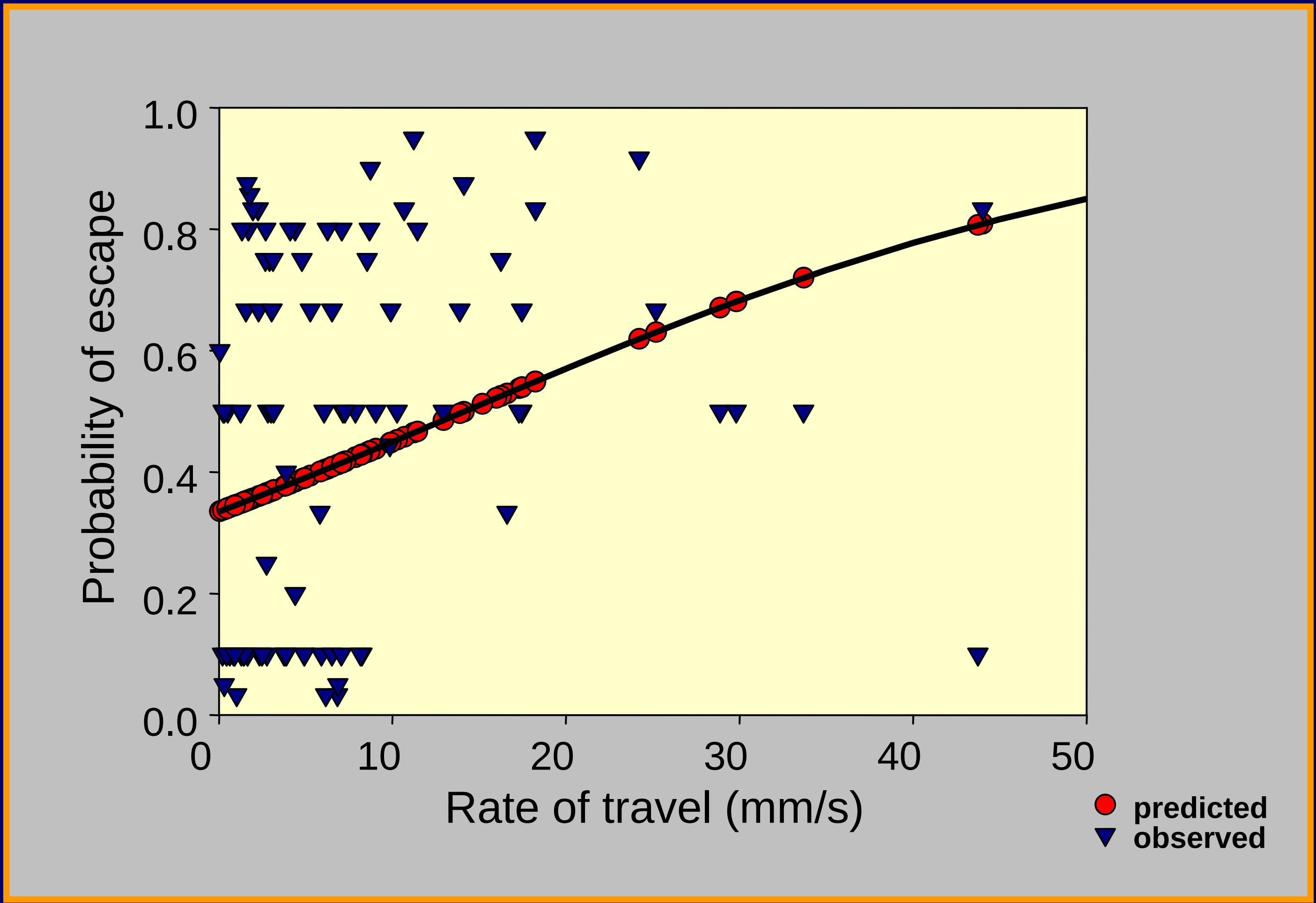
- Logistic Regression
  – Relate swimming speed to the probability of escaping a predator using logits

Regression Tree



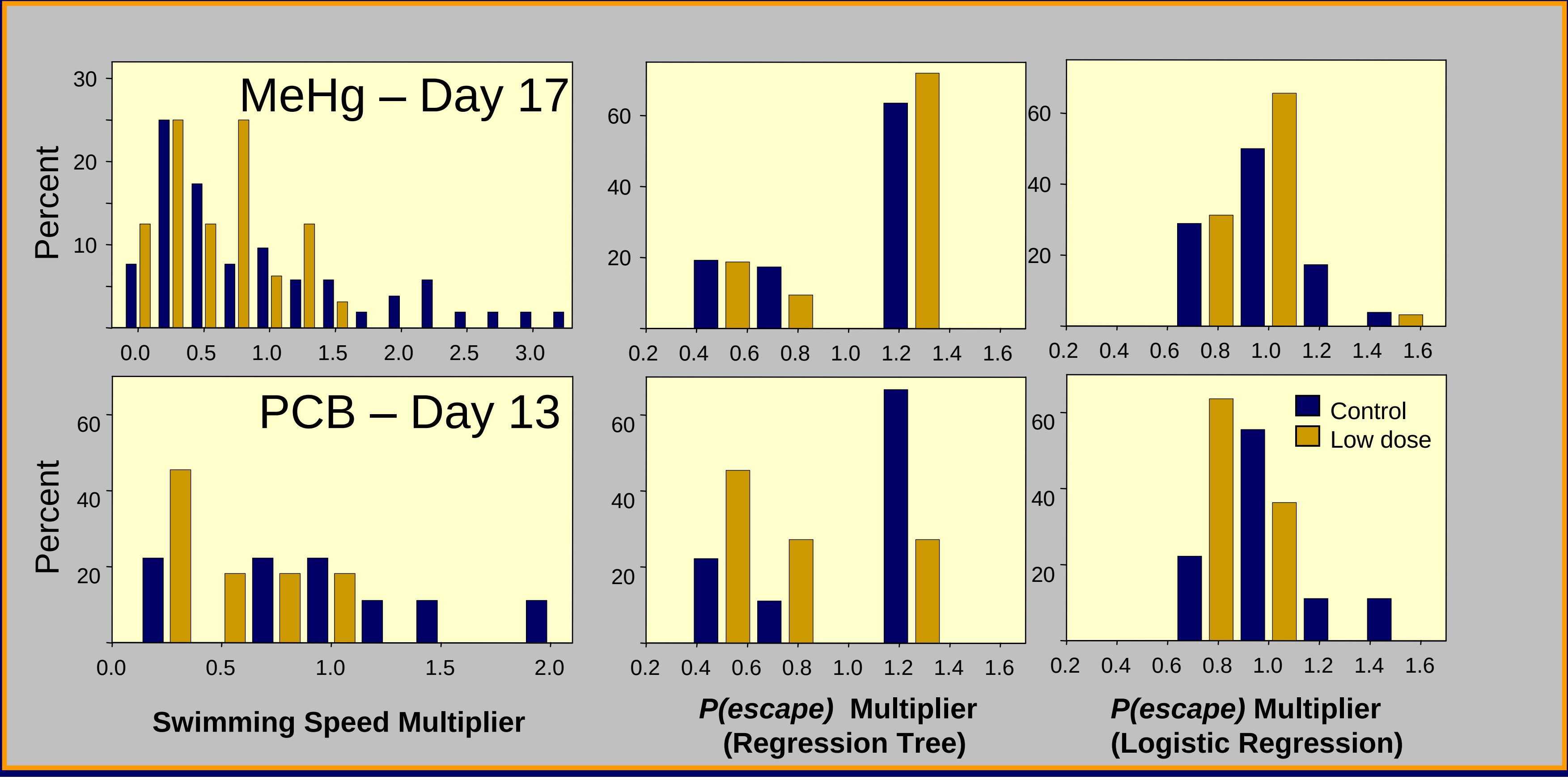
Adapted from Fuiman et al , in press

Logistic Regression

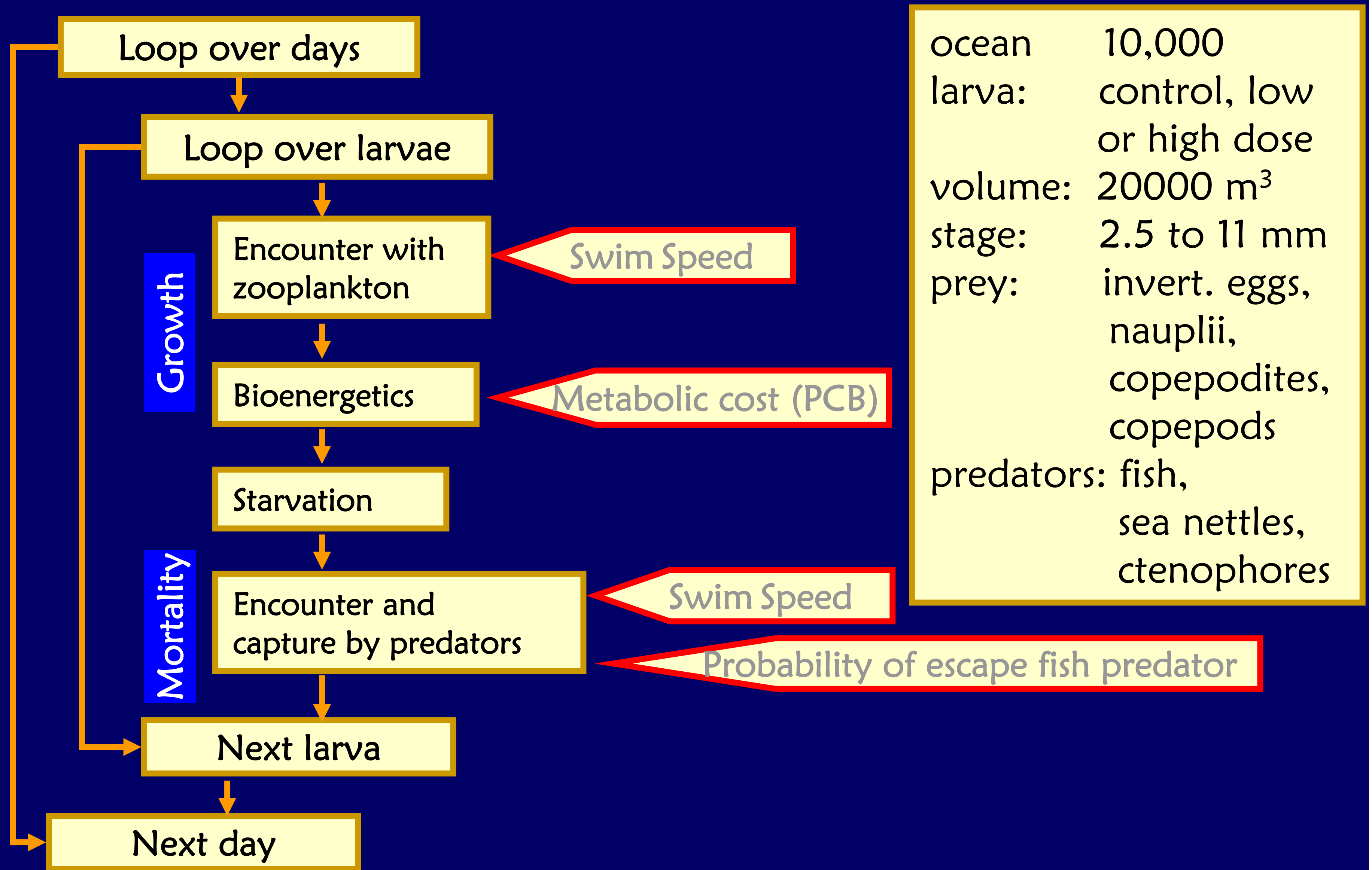


Results: Statistical Models

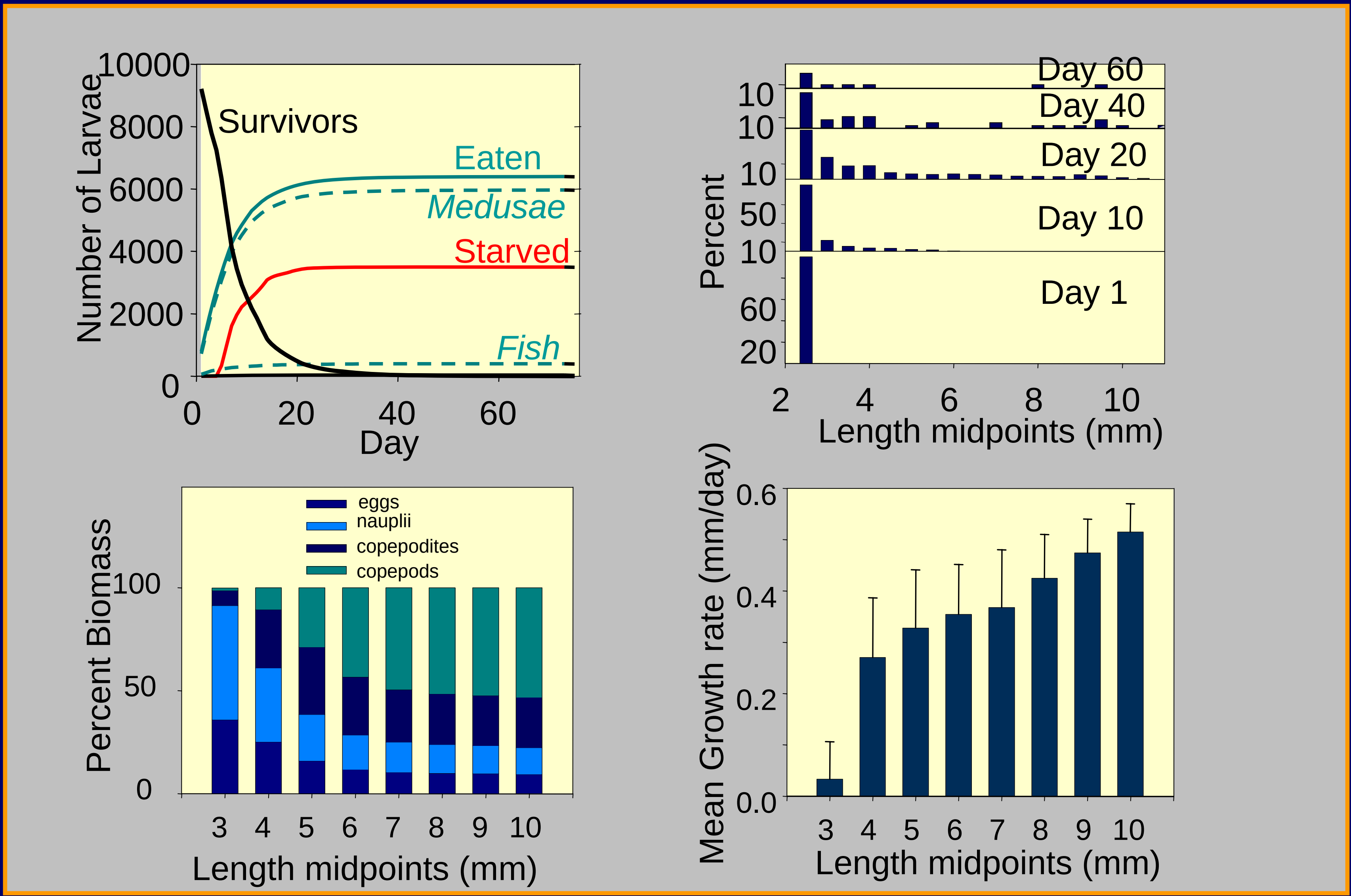
Create multipliers for each developmental stage and each treatment (control, low or high) for swimming speed and the probability of escaping a predator e.g.:



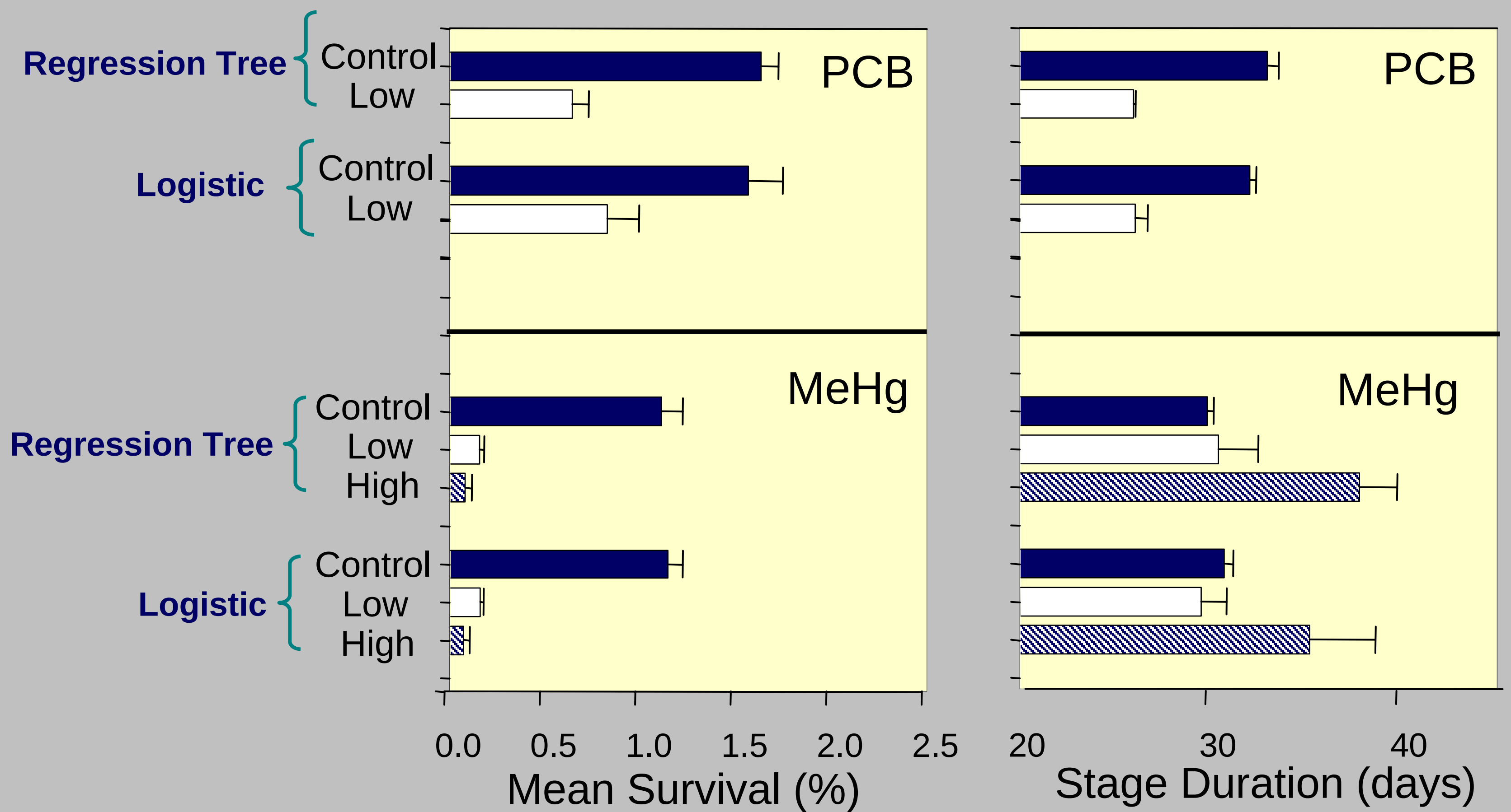
3. Individual Based Model



IBM: Baseline Results



IBM: Summary



Regression Tree
Control
Low
Logistic
Control
Low
PCB
Regression Tree
Control
Low
High
Logistic
Control
Low
High
MeHg
0.0
0.5
1.0
1.5
2.0
2.5
Mean Survival (%)
PCB
MeHg
20
30
40
Stage Duration (days)

4. Matrix Projection Model

Use a matrix projection model to predict population-level responses to endocrine disrupting chemicals from laboratory studies

Matrix Projection Model

Classic formulation:

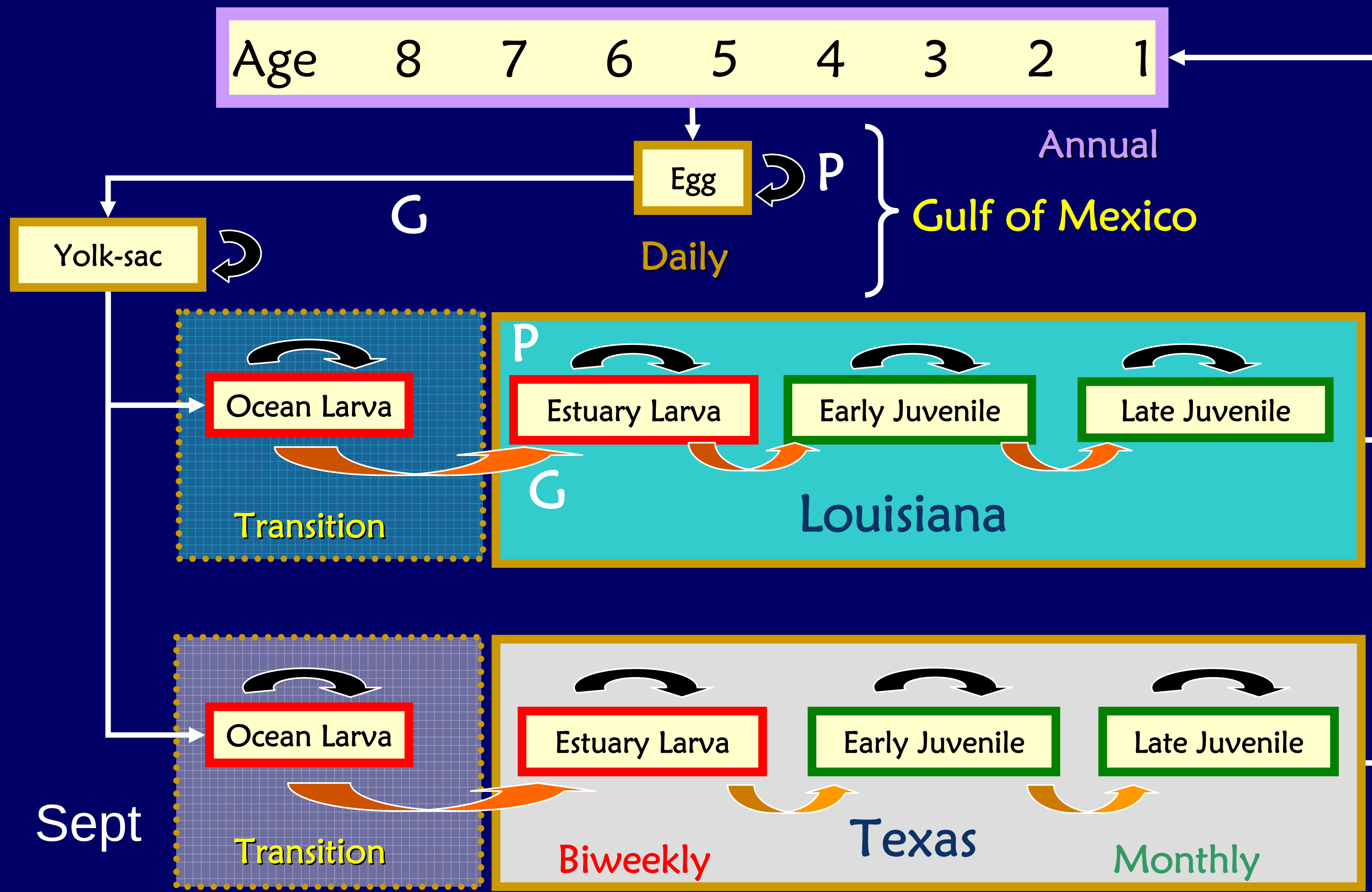
$$\begin{pmatrix} P_{A1} & F_{A1} & F_{A2} & F_{A3} & F_{A4} & F_{A5} & F_{A6} & F_{A7} \\ G_{A1} & P_{A2} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & G_{A2} & P_{A3} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & G_{A3} & P_{A4} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & G_{A4} & P_{A5} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & G_{A5} & P_{A6} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & G_{A6} & P_{A7} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & G_{A7} & P_{A8} \end{pmatrix} \begin{pmatrix} E_{gg} \\ A1 \\ A2 \\ A3 \\ A4 \\ A5 \\ A6 \\ A7 \end{pmatrix}_{t} \Rightarrow \begin{pmatrix} E_{gg} \\ A1 \\ A2 \\ A3 \\ A4 \\ A5 \\ A6 \\ A7 \end{pmatrix}_{t+1}$$

Stage duration and mortality are used to calculate P and G

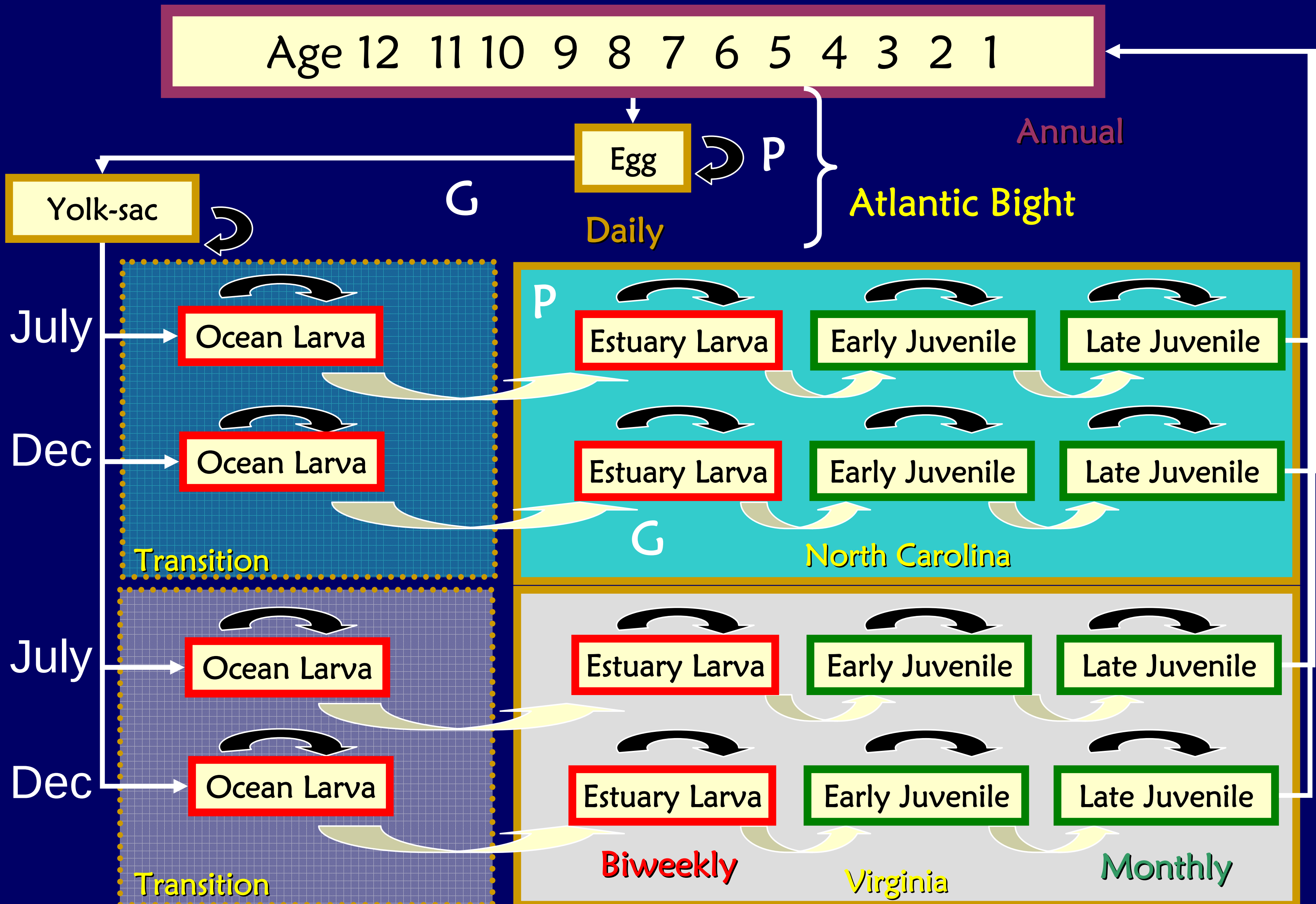
Overview of Approach

- Two Atlantic croaker populations with two nursery areas
  - Mid-Atlantic Bight – North Carolina and Virginia
  - Gulf of Mexico – Louisiana and Texas
- Two contaminants
  - PCBs
  - MeHg
- Different exposure scenarios
  - Contaminants eliminated after first spawning event
  - Contaminant effects last lifetime of fish
  - Percentage of individuals from a nursery area affected

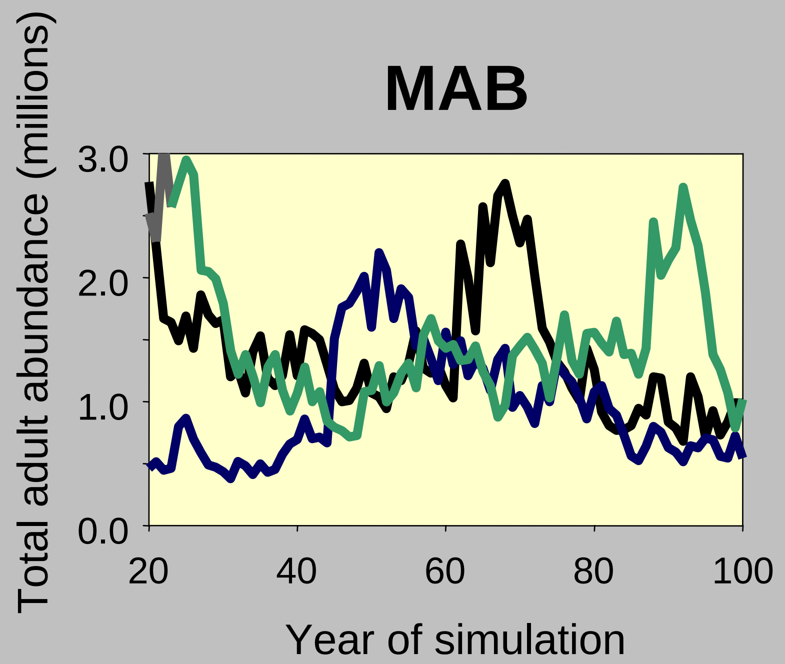
Gulf of Mexico (GOM)

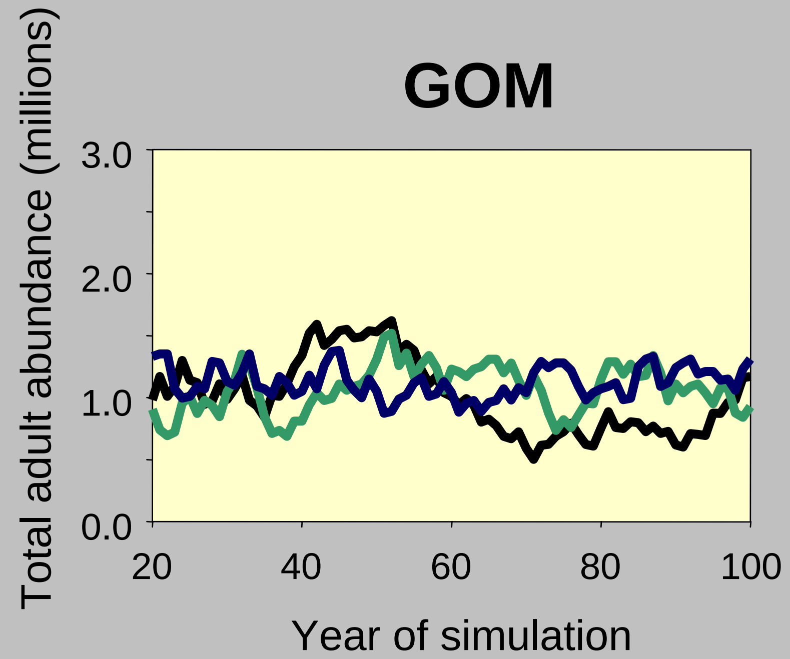


Mid-Atlantic Bight (MAB)

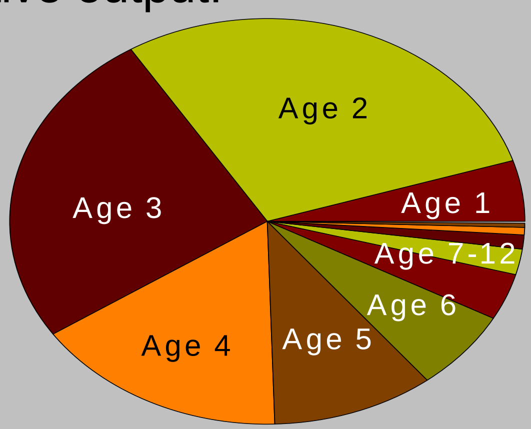


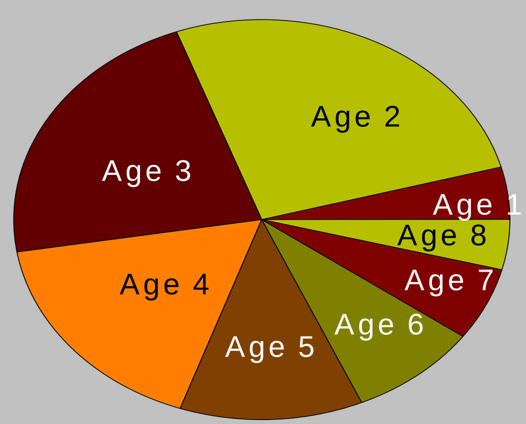
Baseline Simulations





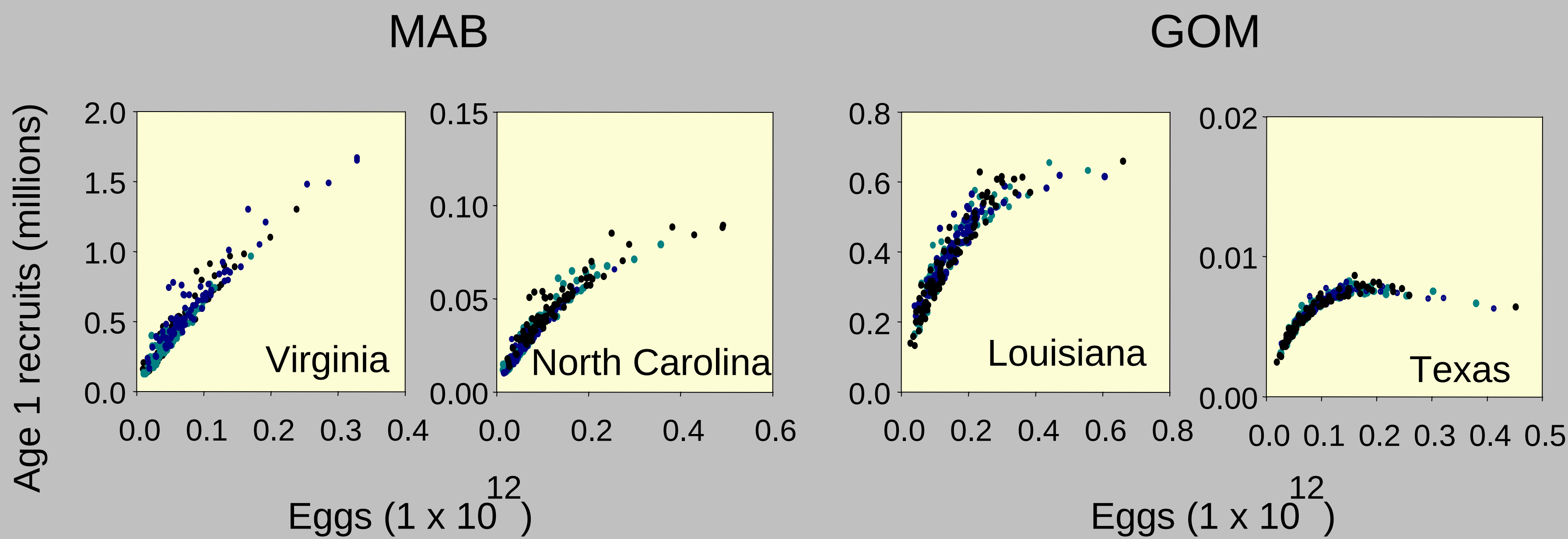
Reproductive output:





Baseline Simulations

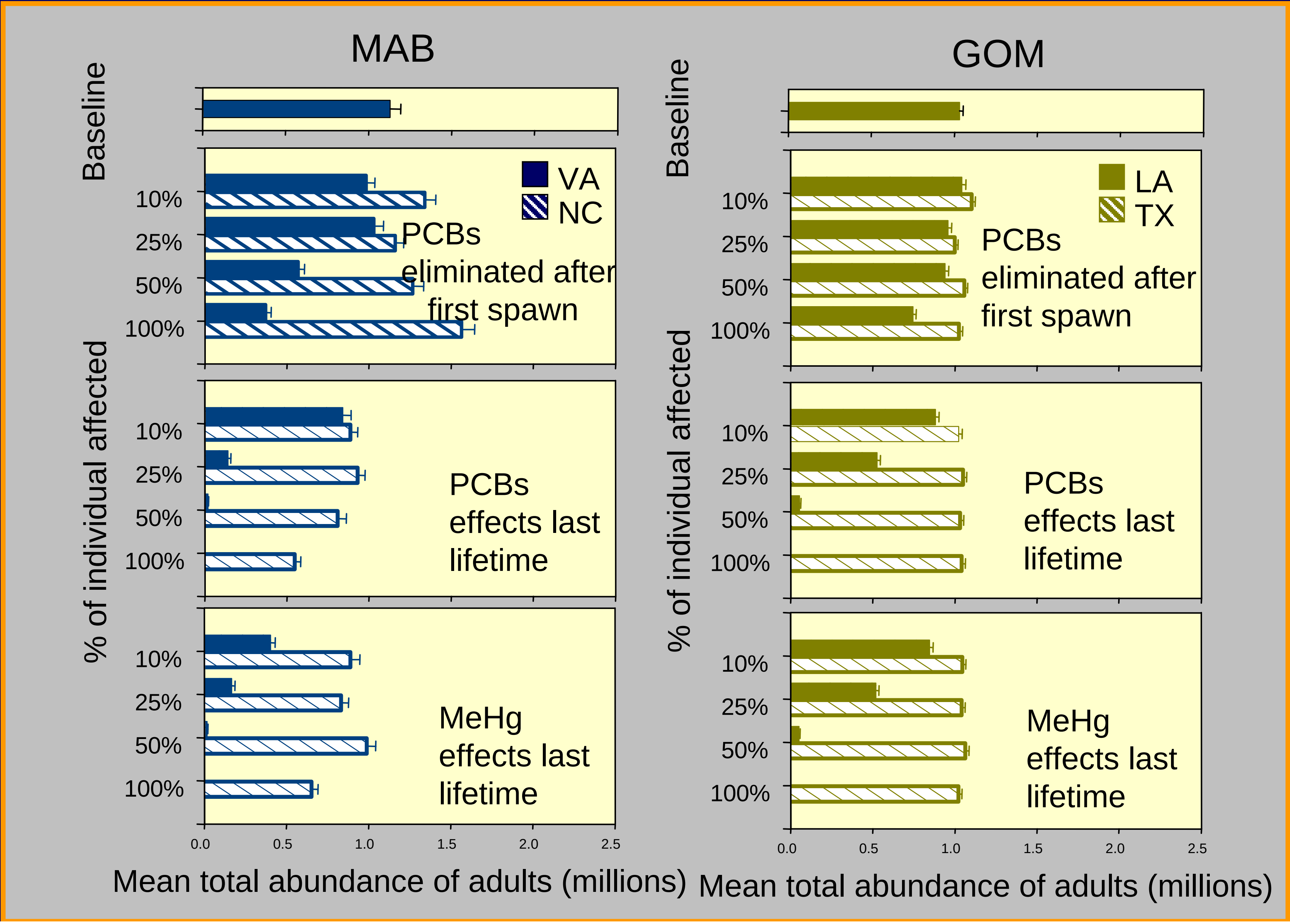
Density dependence: spawner-recruit relationships



Contaminant effects

- PCBs
    - Fecundity is reduced by 65% (Lab)
    - Egg survival is reduced by 81% (Lab)
    - Ocean larva survival reduced by 47% (IBM)
    - Ocean larva stage duration reduced by 19% (IBM)
- MeHg
    - Fecundity is reduced by 33% (Lab)
    - Egg survival is reduced by 45% (Lab)
    - Ocean larva survival reduced by 86% (IBM)
    - Ocean larva stage duration reduced by 4% (IBM)

Simulation results



Conclusions

- Methods:
  - regression tree and IBM – relatively new
  - expansion of classic matrix model – time steps and regions
  - uncertainty and stochasticity embraced
- Physiological model:
  - relate biomarker to ecological endpoint of yolk (fecundity)
  - evaluate biomarkers and multiple stressors in a dynamic system
- Statistical to IBM to Matrix models:
  - laboratory and sublethal effects can be scaled to population level
  - “hundredths of seconds to hundreds of years”